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Improved and Efficient Power and Thruster System for DP Drilling Vessels with New Generation Protection System and Azipod® CZ

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ABB

ABSTRACT

IEC 61850 Communication standard is introduced for marine medium voltage switchboards. This communication standard enables the possibility for the protection relays and controllers related to power management and variable speed drive control to have a direct bus communication.

Using this system in DP drilling vessels has a range of advantages for the installation and operation:

- Reduced internal and external wiring in and to/from the main 11kV SWBD, hence increasing the reliability.
- Enables possibility for fast zone protection (less than 70ms), which can replace traditional busbar differential protection system with its HW components.
- Enables fast communication to Power Management System and Diesel Generator Monitoring Systems. Actions in case of failures can be done faster to prevent unintentional tripping of generators.
- Enables fast communication to drilling and thruster drive systems for fast and accurate load reduction in case of generator and engine failures.
- Simplifies the transfer of statuses, measurements, and logs to supervisory systems to support fault diagnostics and maintenance.

Azipod®CZ is an electric podded thruster with a low voltage permanent magnet electric motor, nozzle, and the whole unit can be tilted to optimize the bollard pull. The unit is available up to 4.7MW and well suited for DP drilling vessels.

The Azipod®CZ design is targeted to maximize the efficiency within the optimization constraints, as well as reducing complexity and simplify installation and maintenance. Considering efficiency of all components and aspects from electric motor and auxiliaries to the hydrodynamic effect of tilting, an annual energy saving of 15% compared to mechanical thrusters can be anticipated given a typical operation profile.

In combination with the new IEC 61850 communication scheme enables an efficient and reliable power and thruster plant for DP Drilling vessels.

1. Introduction

Electric power and thruster systems for DP operated drilling vessels have gradually improved and become more efficient and reliable during the past decades. New products, HW and functionality has become available over the years, and the systems as delivered today are designed for minimizing the risk of blackouts and reducing the start-up time after blackouts. However there is still room for improvements both for the total reliability and also efficiency, which is becoming increasingly more important. In this article we will present the benefits and improvements by the introduction of new protection relay series with fast bus communication on the IEC 61850 standard, and the utilization of the energy efficient Azipod® CZ thrusters.

The new generation of protection relays with the possibility to communicate on the IEC 61850 standard opens up new possibilities for optimizing the power plant design and increasing the level of safety [1]. First of all the bus communication between each relay and to/from IAS/PMS simplifies the construction of the switchboard and nearly removes the need for auxiliary and signal wirings internally and externally. Further integration with PLCs also communicating on the same standard, makes it easier to include additional supervisory protection functions as Diesel Generator Monitoring System (DGMS), and Power Management Systems (PMS) both physically and functionally into the main SWBDs.

Further, the communication and integration can easily be extended to include also power consumers using variable speed drive controllers, such as thruster and drilling drives. This opens for new opportunities to improve the functional integration of load control and blackout prevention, and the fast communication between the power producing elements and the consumers gives benefits for fast load reduction and reduced risks for blackouts or partial blackouts.

Azipod®CZ is an electric podded thruster that is specially developed for optimized bollard pull for drilling vessels [2]. By the combination of the use of direct motor connection, permanent magnet motor technology, tilting of the complete thruster unit, and a minimum of auxiliary components, up to 15% yearly energy savings can be achieved compared to mechanical L-Drive thrusters for a given operation profile. With the current solution, Azipod®CZ provides a simple interface for the customer as only the steering and propulsion drives are the main components to be integrated to the ship power system.

In this article we will first describe the characteristics of the new protection relays and the power system configuration, and then continue with discussing the benefits this system enables for a better performance and reduced risks for blackout. Then the main benefits of Azipod®CZ is discussed, and with special attention to energy saving and simplicity of installation.

2. New Generation Protection Relays and IEC 61850

The introduction of the IEC 61850 standard represents a technology milestone in power plant automation by simplifying the integration of protection relays and power plant as well as process automation. The standard defines the communication system, data models and abstract services to access data which ensures the interoperability between devices. In IEC 61850-based architectures, conventional wiring has been eliminated and these signals are transmitted and received via the communications interface. Thus, the communication interface in the new IEC 61850-based IEDs (Intelligent Electronic Devise) must be very efficient at processing the communication data. Two communication methods for data exchange are applied:

- MMS –Client / Server Communication specifies a method of exchanging non-time-critical data through local-area networks. The use of MMS allows provisions for supporting both centralized and distributed architectures. This standard includes the exchange of real-time data, indications, control operations and report notification.
- GOOSE –Publish / Subscribe Communication. GOOSE (Generic Object Oriented System Event) is used to model the transmission of high priority information like trip commands or interlocking information. The model is based on cyclic and high-priority transmission of status information.

IEC 61850 uses Ethernet as the basic communication technology. In order to ensure high performance and reliability in the communication a switched Ethernet network architecture is used. Benefits of a switched Ethernet network architecture include:

- Real-time network performance to develop deterministic systems.
- Security &Reliability.
- Manageability and ease-of-use features.
- Flexible communication topologies.
- Use of standard Ethernet protocols,
  e.g. SNTP for time synchronization, SNMP for network supervision, QoS to priories transfer of time critical data.

2.1 ABB's Relion® protection and control product family

ABB's Relion® protection and control product family was one of the first to undergo the IEC 61850 transformation and was designed from the beginning for a native implementation of IEC 61850. The new platform architecture integrates communication services and data representation into the core protection and control applications. Protection and control algorithms, which provides the protection relay core functionality, are modelled and implemented fully according to IEC 61850 standard rules. Thereby the data models are supported directly in the protection and control functions and the data is directly accessible from the communication services. No time consuming additional data mapping and conversion processes are required, making the data in the protection relay directly available which is a key factor in communication performance.

2.2 IEC 61850 Communication, GOOSE

As communication method in a medium voltage switchboard between protection relays as well as high priority information to the automation system, GOOSE is used. GOOSE messages are user defined data. When a change in a contained data item is detected, the data is send immediately at a high priority. The data is sent multiple times to ensure reception of the data, Figure 1.

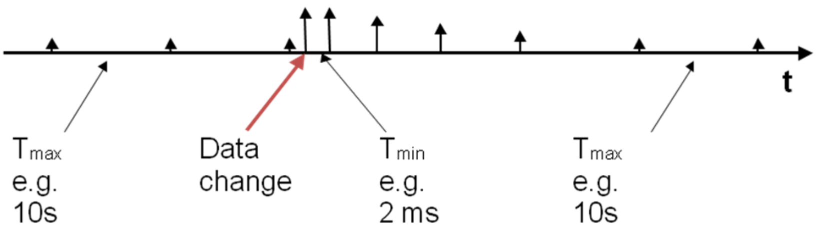

Figure 1 *GOOSE communication time line [1]*

GOOSE provides the fast peer-to-peer information exchange between the output data values of one IED to the input data of many other IEDs (multicast) based on publisher and subscriber mechanism. In principle all measurement and status values can be shared between IEDs and IEC 61850 supporting control systems. GOOSE communication replaces hardwired signals within the switchboard and towards the automation system and makes more information available without need for additional hardware.

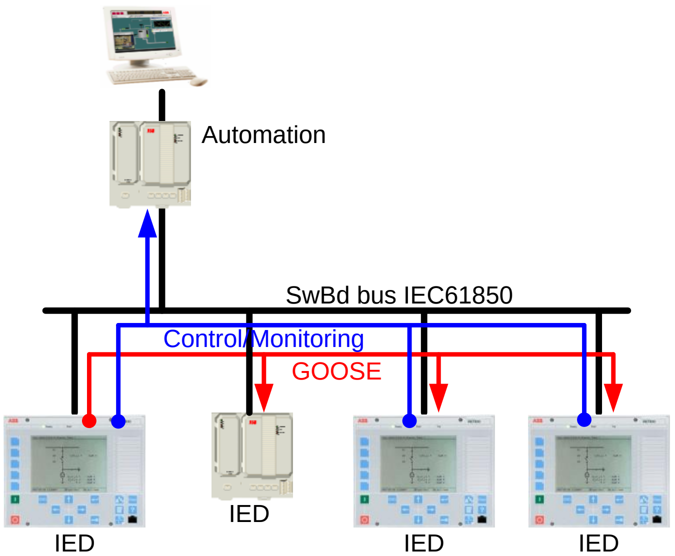

***Figure 2** Typical communication topology [1]*

Following the IEC 61850 standard means that peer-to-peer signalling is faster than traditional hard-wired loops. ABB's new Relion® 615 and 630 series products achieve the performance class T1AP1 with transmission time <10ms in all operating conditions. With communication performance and increased amount of signals available between protection relays makes more advanced protection schemes are feasible.

Further benefits of GOOSE communication are:

- Automatically supervised connections
  - Connection failures are always detected
  - Data quality sent to peer IEDs along with event to enable data validation
  - Preconfigured fail-safe value in case of failure
  - Indication of communication loss
- More I/O without hardware changes or additions
- Expandability
  - IED retrofit installations with just small wiring changes
  - New functionality can be introduced
- Flexibility
  - Possibility to easily add functionality afterwards
  - IEDs can share unused I/O

2.3 Utilizing IEC 61850 in Marine Switchboard Design

Utilizing IEC 61850 in a marine switchboard introduces a common switchboard communication network. The switchboard network is designed as private and isolated local area network (LAN). On the physical layer the Ethernet network operates with a speed of 100 Mbps in full-duplex. A switched Ethernet configuration is used where all devises are cross connected through switches. The arrangement of Ethernet switches and the connection between them defines the network topology. A switched Ethernet provides a fast and reliable transmission by giving each device full bandwidth in both transmission directions and forming a collision free domain. This configuration is crucial to fulfil the requirements for time critical signal transfer in IEC61850. Redundancy is managed within the communication network by connecting the Ethernet switches in a multiple ring topology. Every Ethernet switch has two inter-switch links and thus any two end nodes (IED, controller, PC, etc) which are not connected to the same Ethernet switch have two paths between them when all components are in operation.

All signal transfer between protection relays, signal interface to the automation and monitoring system as well as data communication for diagnostic and service purpose will use this common communication infrastructure. With fast peer-to-peer communication available between protection relays new switchboard protection schemes are feasible. Figure 3 shows an example set-up of IEC 61850 configuration in a marine power system.

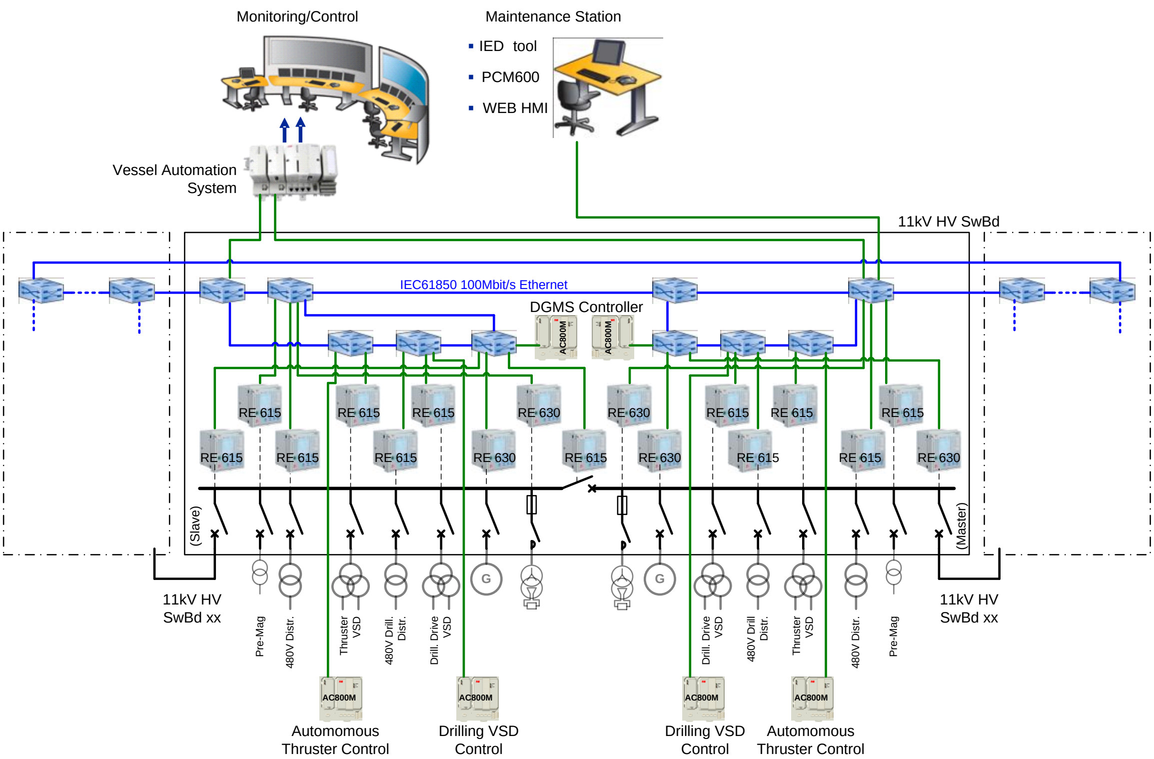

__Figure 3__ Typical configuration for a drilling vessel (one of multiple SWBD sections)

Advantages:

- One communication network with one communication standard only
- Ring communication topology providing network redundancy
- No hardwired signals
- Every signal between protection relays and to PLC controller is loop monitored
- Fast peer-to-peer communication between relays and to PLC controller
- More information available
- New switchboard protection schemes
- Accurate time synchronization

Following two examples illustrates the possibilities:

Example 1:
Switchboard earth fault zone protection (see Figure 4): Switchboard requires multiple signal connection between protection relays within and between switchboard sections. With IEC 61850 all signal are send through GOOSE messaging. In difference to traditional hardwired solution the signal are loop monitored which reduces the risk for hidden system and component failures.

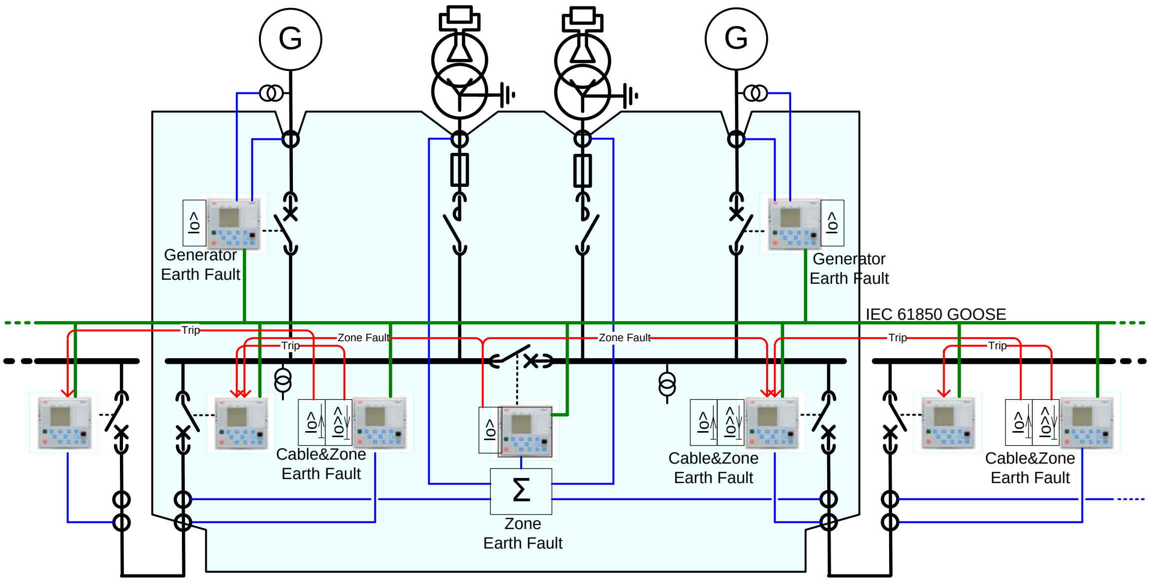

***Figure 4** Example earth fault switchboard zone protection*

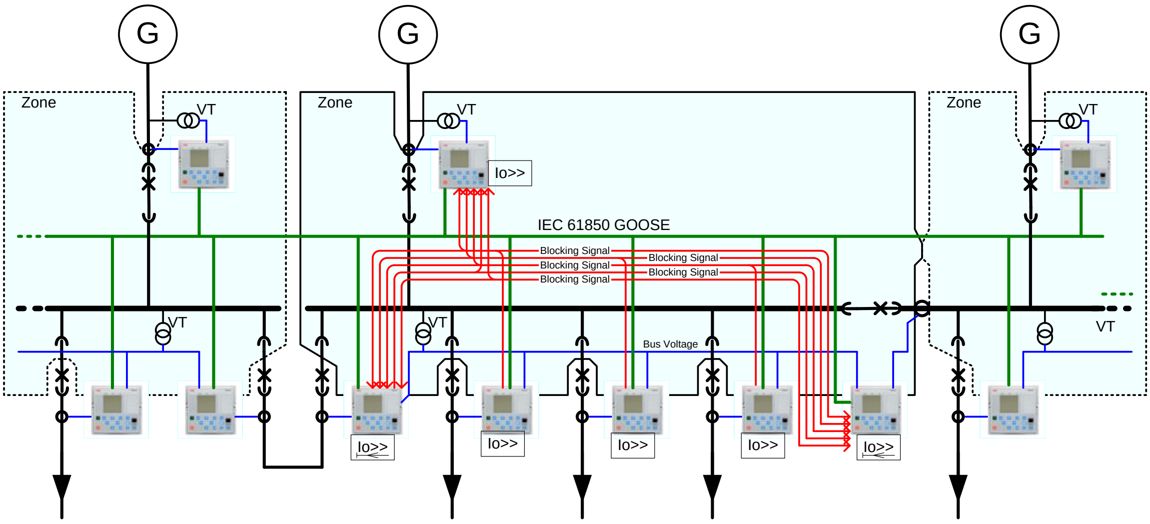

***Figure 5** Example short circuit switchboard zone protection*

Example 2: Switchboard short circuit zone protection (see Figure 5): Blocking based protection schemes are well-known and widely accepted. When a fault occurs on an outgoing feeder, the protection and control IEDs of both the incoming feeders and the faulty outgoing feeder start. On starting, the IED of the outgoing feeder, however, blocks the fast-acting stage of the incoming feeder IEDs. On the contrary, should a fault arise on the busbar system, the outgoing feeder IEDs will not start and the incoming feeder IED is allowed to operate after a short coordination time delay and trip the CB of the incoming feeder. With IEC 61850 all signal are send through GOOSE messaging. Due to the amount of signals between the protection relays blocking based protection scheme is feasible in bigger scale.

Advantages:

- Fast, robust and easy to install busbar protection scheme
- Independent of central unit
- No additional differential protection CTs and compensation circuits needed
- Fast fault clearance time in the range of 150ms, reducing the network disturbance
- Less wiring, less components

- Loop monitor and heartbeat signals between relays and self-supervision, reduces risk of hidden system and component failures
- Breaker failure detection with protection tripping decision as alternative action to remove the failure

2.4 Interface and integration with power plant control and monitoring systems

In a traditional power system for marine vessel the main protection of the power plant is composed of the protection relays mounted on each feeder and incomer of the main switchboard. Further a higher level Power Management System is installed for overall power control and monitoring. Lately more advanced protection schemes are introduced (as Diesel Generator Monitoring Systems, DGMS) in order to monitor and respond to failures that are not directly observed by the protection relays. This is typical PLC based control on a similar level as the power management system, however with more direct interface to the switchboard variables in general and generator variables in particular. However a proper communication and interface to the PMS and also the vessels automation system is needed. By using the IEC 61850 communication and the relays and PLCs being able to communicate directly on this standard, the possibility of having all these three usually separate systems on the same communication network is enabled. Even further, this will also enable the possibility of physically integration of the units inside the main switchboard reducing the requirements for the shipyard for installation and cabling. Figure 6 shows a configuration diagram with a proposed interface connection between these systems.

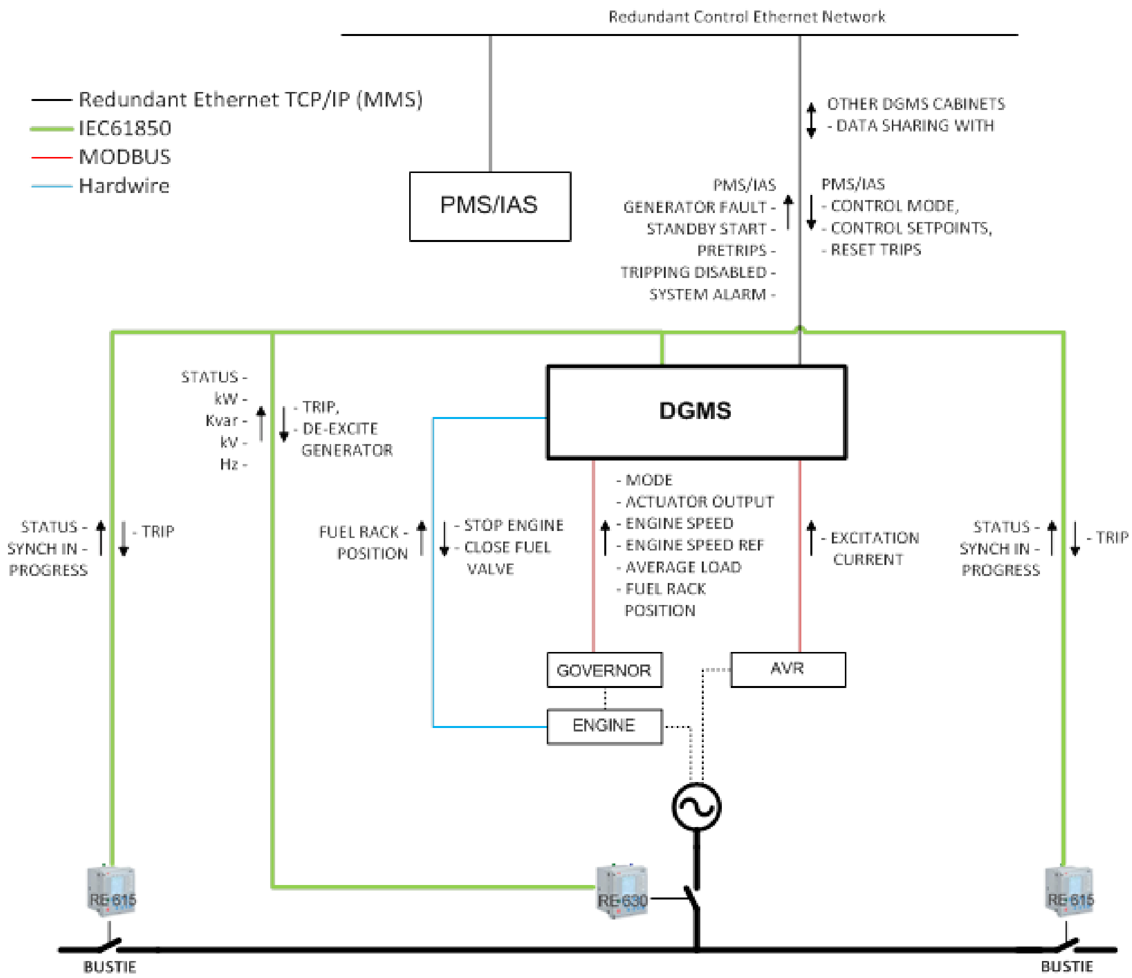

***Figure 6** Diesel Generator Monitoring System integration scheme*

2.5 Interface to variable speed drive controls

With the IEC 61850 communication standard also other systems like variable speed drive controllers can easily be hooked up on the same network. This means that in practice all information and variables in the power systems are known also for the consumers. This can be utilized to design load reduction schemes that are tailor-made for any event that may occur on power generation side, reducing the risk for blackouts and partial blackouts. Both the thruster drives and drilling drives have controllers that can communicate on this standard and Figure 7 shows a typical configuration for such an integration scheme. The timeline is shown in order to indicate that in case of circuit breaker trip actions and response in the variable speed drive system can be initiated somehow within 50ms, which in fact is at similar time needed for the circuit breaker to physically open.

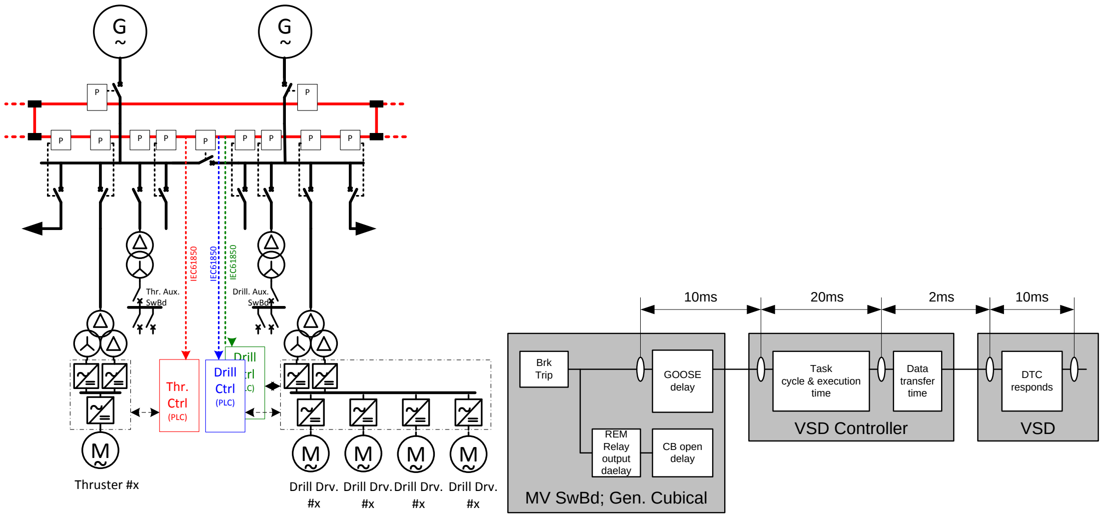

Figure 7 *Variable speed drive integration scheme with example time line.*

3. Azipod® CZ – Saving space, saving money – decreasing components

This chapter present new possibilities to enhance drilling vessel space utilization as well as efficiency of the whole thruster system. With the current solution Azipod®CZ provides a simple interface for the customer while steering and propulsion drives are the main components to be connect into ship power supply. Figure 8 compares amount of components in Azipod®CZ and Mechanical L-drive. As seen Azipod® is relatively simple comparing to L-drive solution caring huge amount of auxiliary components. This is one aspect that is typically not taken into consideration as a possibility for modern drilling vessel. In addition to this there is no need for hydraulic piping providing easier and cheaper installation. While the pod is used for thruster use only, second steering drive could be left out while one steering motor is carrying the needed steering load. That leaves the redundancy needed for single thruster to be carried out by system level e.g. by multiplying the amount of thrusters needed in any case.
One step further, for simplicity and space saving, by combining propulsion and steering drives under the same unit some more cost savings can be achieved. With multi-drive concept steering and propulsion is combined under one cabinet. Even though drive foot print will increase the need for low voltage supply switchboard would be smaller providing savings in cabling and installation costs. Also if voltage supplies for the auxiliaries would be supplied through one cabinet that would give one simple interface to the power system. The same cabinet may also be used for I/O interface e.g. for ship automation and remote control.

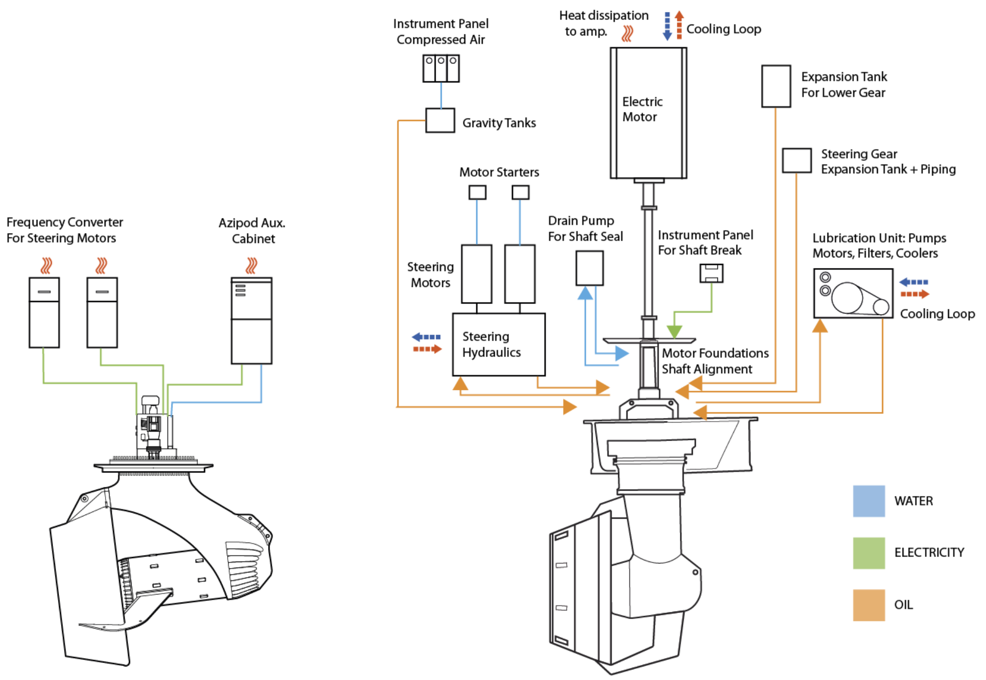

Figure 8 *Azipod® CZ vs. Mechanical L-drive with auxiliaries*

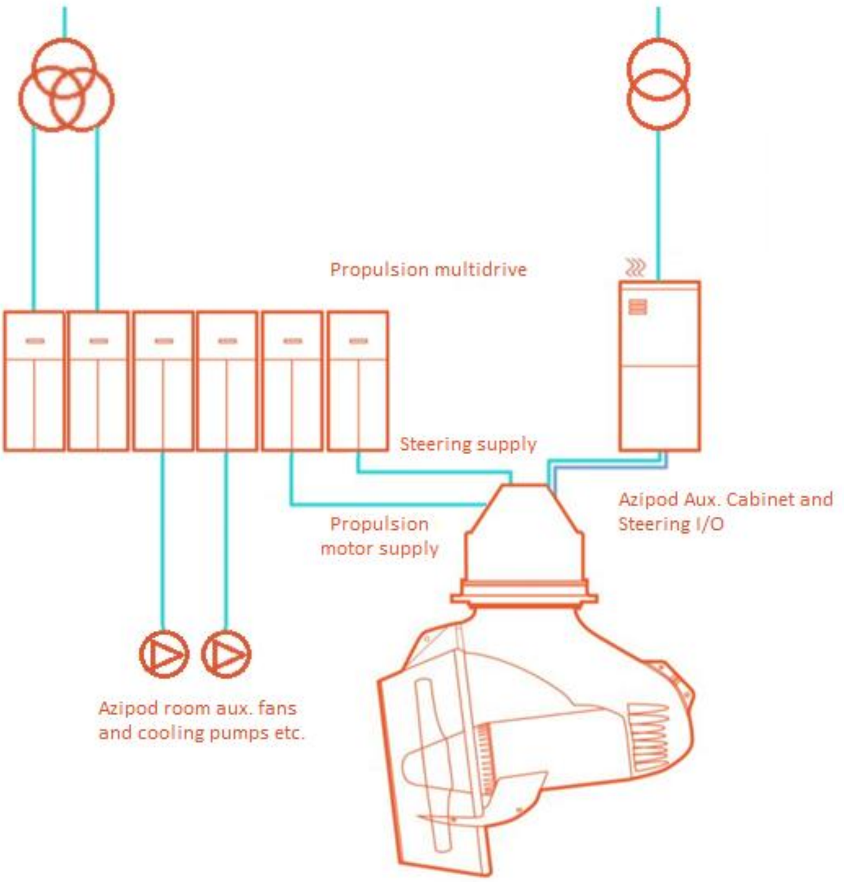

Figure 9 *Multidrive concept*

The Azipod® room itself requires also ventilation, normally provided with separate power supplies that are typically supplied from auxiliary switchboard. By combining also these into one multidrive some more savings in cabling in addition to installation work will be gained. Cabling has a huge cost saving potential, since the low voltage switchboards are often distant from the load; for example in semi-submersible rigs, they may be located at the main deck while the thruster rooms with the auxiliary drives are down in the pontoons. With this solution hundreds of meters of cables can be avoided. Beside to these, fans and pumps (if needed) can be controlled according to the actual ventilation need at a time instead of running them with full power continuously. As pumps and fans are dimensioned to the requirements of full capacity; they are over dimensioned for the normal load requirements and hence wasting energy if they are run at fixed speed. As the auxiliary basically are used all the time in DP operations, the energy saving is significant if the load can be controlled with variable speed.

3.1 PM motor efficiency – High result with effective motors

Since the thruster load profile has a huge impact for the operating cost and fuel consumption, the efficiency of the motor makes a direct impact on energy losses. Using permanent magnet synchronous motors, the motor efficiency is higher than other feasible alternatives; and together with the non-geared mechanical transmission from motor to propeller, the energy efficiency from the electric supply to the shaft power is higher than in any geared thruster concepts. Also, the heat produced by the motor is cooled directly into sea water, which reduces the cooling demand within the thruster room. The following drill-ship concept calculation shows the savings in real values.

An evaluation is made to compare yearly energy consumption of two different concepts of propulsion with 6 x Azipod® CZ 4.5 MW thrusters and 6 x Mechanical L-drive 4.5 MW thrusters. The operational profile is based on assumption that 5% of the yearly operation, the vessel is in transit with full speed, while the remaining 95% is divided to DP operation according to statistical multiyear share from similar units on DP vessel. Also 90% of the time of DP operation the thrusters are operating with less than 100 rpm propeller speed (< 15% of rated power). The result of that comparison is that the Azipod®CZ thruster is about 7% more efficient on drill ship operation than an L-drive thruster; only considering the higher efficiency of the permanent magnet motor compared to an induction motor, in particular at low loads as shown in Figure 10. With 330 USD/MWh energy cost, this reduce the yearly energy costs about 480,000 USD.

3.1 From small creeks into great river - PM auxiliary losses

As the Azipod®CZ has fewer auxiliary components than a mechanical L-drive thruster, there is also a difference in their power consumption, which over time adds up to a significant energy difference. The following model presents losses including also those additional sources which often are disregarded, though important enough, when comparing the different drive systems.

A mechanical thruster system will have high auxiliary power consumption. In particular in part load operation (as most of the DP operation is) it is more dominant, see Figure 11. Therefore, also such components as cooling fan lube oil pumps etc. were taken into account on this analysis. The aim was to be able to compare on an ”apple to apple” basis – by including also all auxiliary power loads; while the losses that are equivalent, such as transformer losses, electric power transmission losses etc. were disregarded. As a conclusion the analysis shows that there is potential of annual savings of thruster energy consumption of 3-7%, from the reduced auxiliary loads alone, by using the use of Azipod®CZ thrusters.

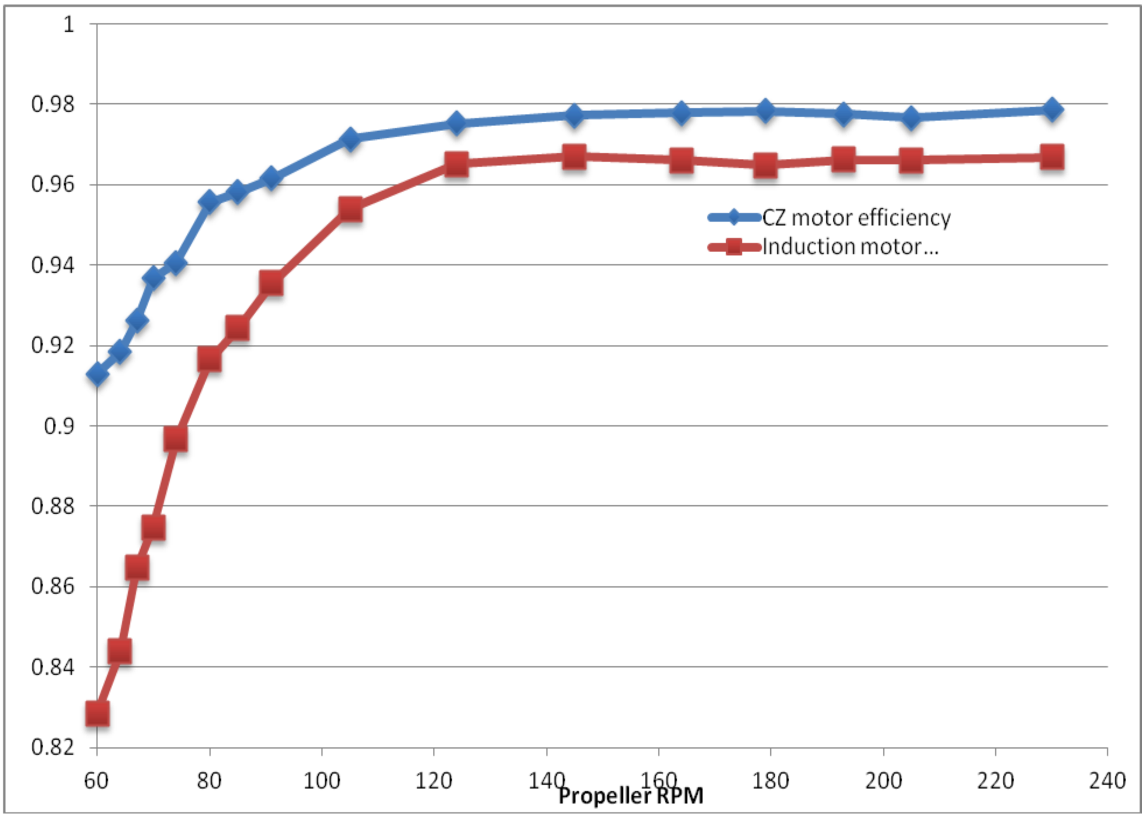

Figure 10 *Electric motor efficiency curves induction motor vs. permanent magnet motor*

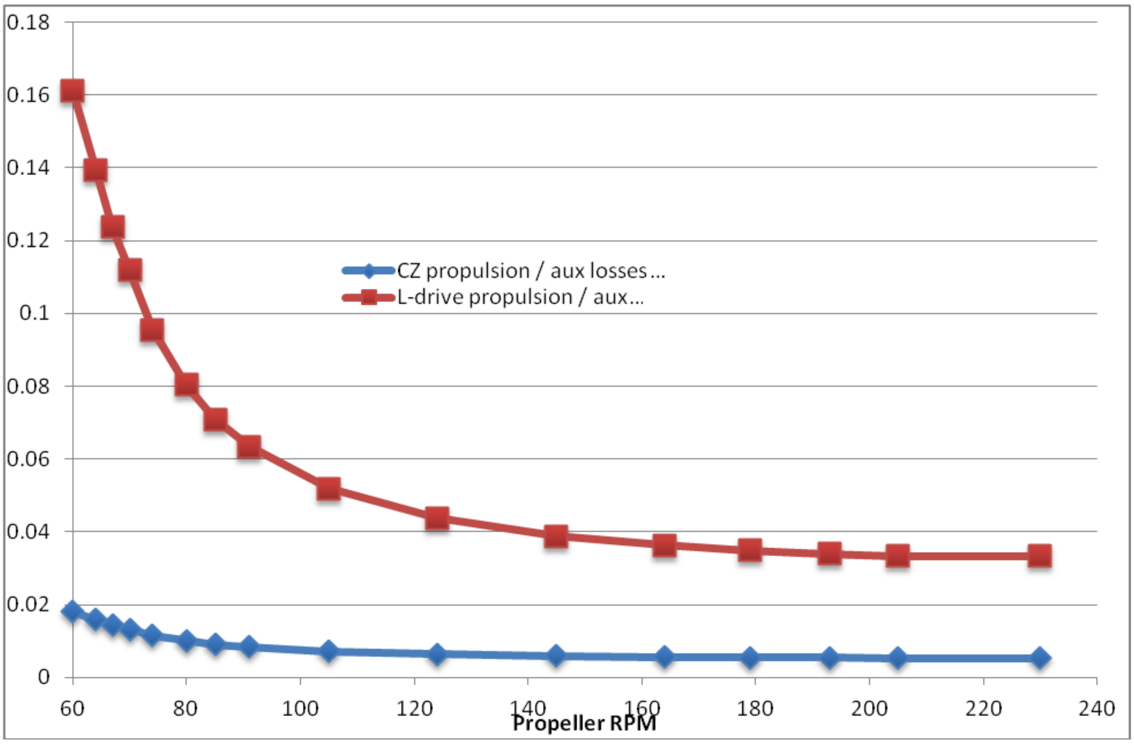

Figure 11 *Auxiliary losses in relation to actual power at specific load point.*

3.2 Hydrodynamic Benefits

The Azipod®CZ has a non-geared mechanical transmission to the propeller, with a 7 degrees tilt angle of the propeller shaft in order to reach a higher hydrodynamic efficiency. The tilt angle leads to reduced interaction with the hull or pontoon and other thrusters, and reduces the interaction to hull known as Coandă effect. Until recently, and still for some products applied today, the mechanical L-drive thrusters have approached this problem by tilting the nozzle, while the propeller shaft is horizontal. The difference in losses with a tilted nozzle versus a tilted shaft line gives a difference in the thrust in the range of 4 to 8% for the same shaft power load. Designs with horizontal shaft line, and non-tilted nozzle is not a viable alternative, as the hull and thruster interaction losses may range to 10-30% of loss in the thrust.

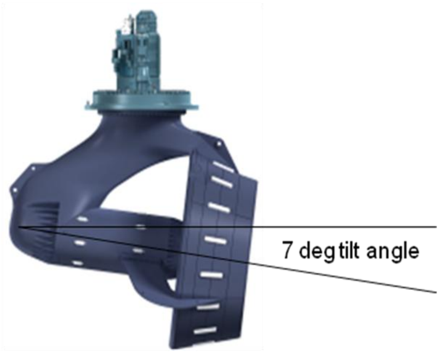

Figure 12 *Azipod® CZ with tilt angle*

4. Concluding Remarks

The introduction of the IEC 61850 communication standard into marine power systems opens many new ways of optimizing the total performance of power systems for marine vessels. For DP class drilling vessels the standard enables fast and accurate communication between the primary protection system and upper level protection systems (as PMS and DGMS) for the power plant. For shipyards it means less cabinets and less wiring. For the operators it means more accurate and faster protection functionality, which will reduce stress on component in a failure mode situation. Further integration with variable speed drive controllers which communicates directly on the same communication network, enables possibilities for fast and accurate load reduction schemes, in case of power plant and generator failures.

It is shown that the efficiency of an Azipod®CZ thruster is better than that of a mechanical thruster considering the various factors as electric motor type, auxiliary power consumption, mechanical transmission, tilting of the propeller shaft, and hydrodynamic considerations. The potential of energy saving and possible reduced installed power capacity depends on many factors, and should be checked from case to case. We have in this article highlighted the characteristics of the Azipod®CZ thruster with possibilities for energy and space saving. A feasible and obtainable reduction in thruster energy usage in the order of 15% has been shown, by using Azipod®CZ compared to mechanical thrusters. This is a result of electrical and hydrodynamic efficiency; and being dependent on the thruster load profile.

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[1] Special Report IEC 61850; ABB Review; 2010; ISSN: 1013-3119

[2] Tiainen, L, Jehkonen, T., Hansen, J.F.; Simplifying Energy Efficiency; Generations Magazine; Issue 1 -2012; ABB Marine and Cranes; 2012.